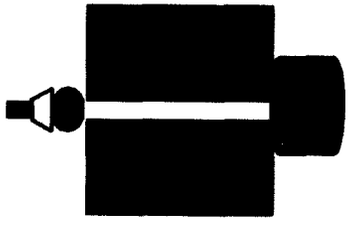
# Fission Nuclear Electric Propulsion and MagOrion: Toward an Interstellar Capability

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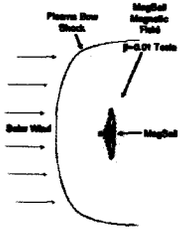


# Outline

- Historical Perspective
- Assessment of Systematic Problems
- Prior Solution
- MagSail – Answering the Difficult Issue
- Performance Potential
- Summary

# Historical Perspective

- Attended 1996 CalTech Interstellar Conference
- Numerous High Technology Schemes Proposed
- Appeared to be Extremely Long-Term and Very High Risk
- Some did not Appear to be Achievable Even in Long-Term
- Evaluated Potential of "Forward Runway" Concept to Fission NEP
- Presumed Macro-Particle Accelerator Provide U-235 for Acceleration from Earth and Deceleration at Target Star System .
- Involved Very Large Masses of U-235 on Spaceship to Decelerate at Target Star System (-12,000 T)

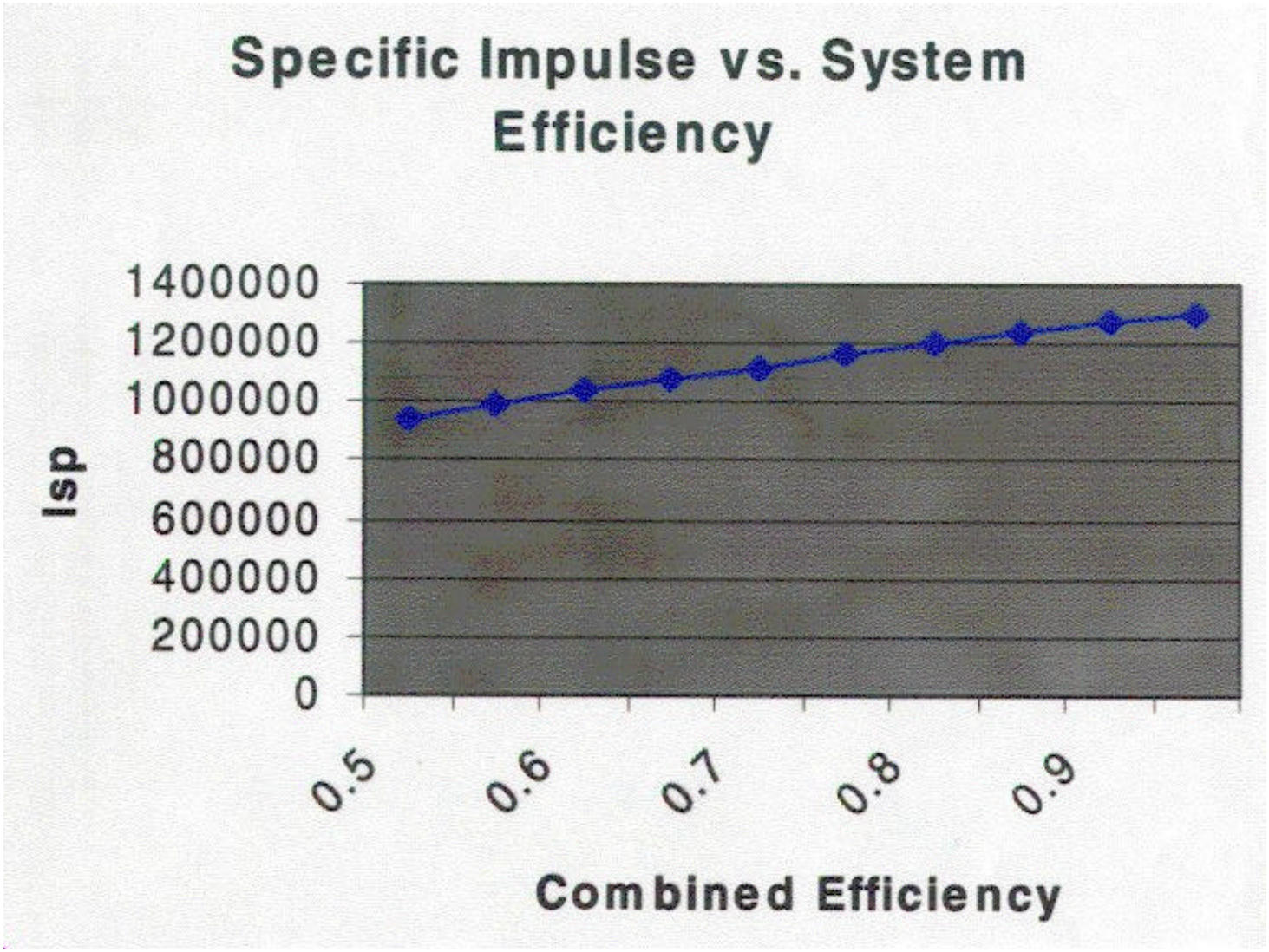
# Systematic Problems

- Technology Issues:
  - High Power Macro-Particle Accelerator
  - 20 TW Beam Power
  - Accelerate 12,000 T U-235 to 0.1c in few Months
  - Extremely High Power Density Nuclear Electric Propulsion System: a- $1 \times 10^{-4}$ kg/kWe
  - Continuously Fuel-able Reactor
  - Fission Products as Ion Propellant
  - U-235 “Catcher’s Mitt” on Spacecraft
  - High Efficiency Ion (Fission Product) Engines
- Crewed Spacecraft weight: 200T
- Total Spacecraft weight: 1000T
- Maximum speed: 0. 1c
- Subject to Unknown. Aiming Errors for Particle Accelerator
- Bulky and cumbersome but appears to work

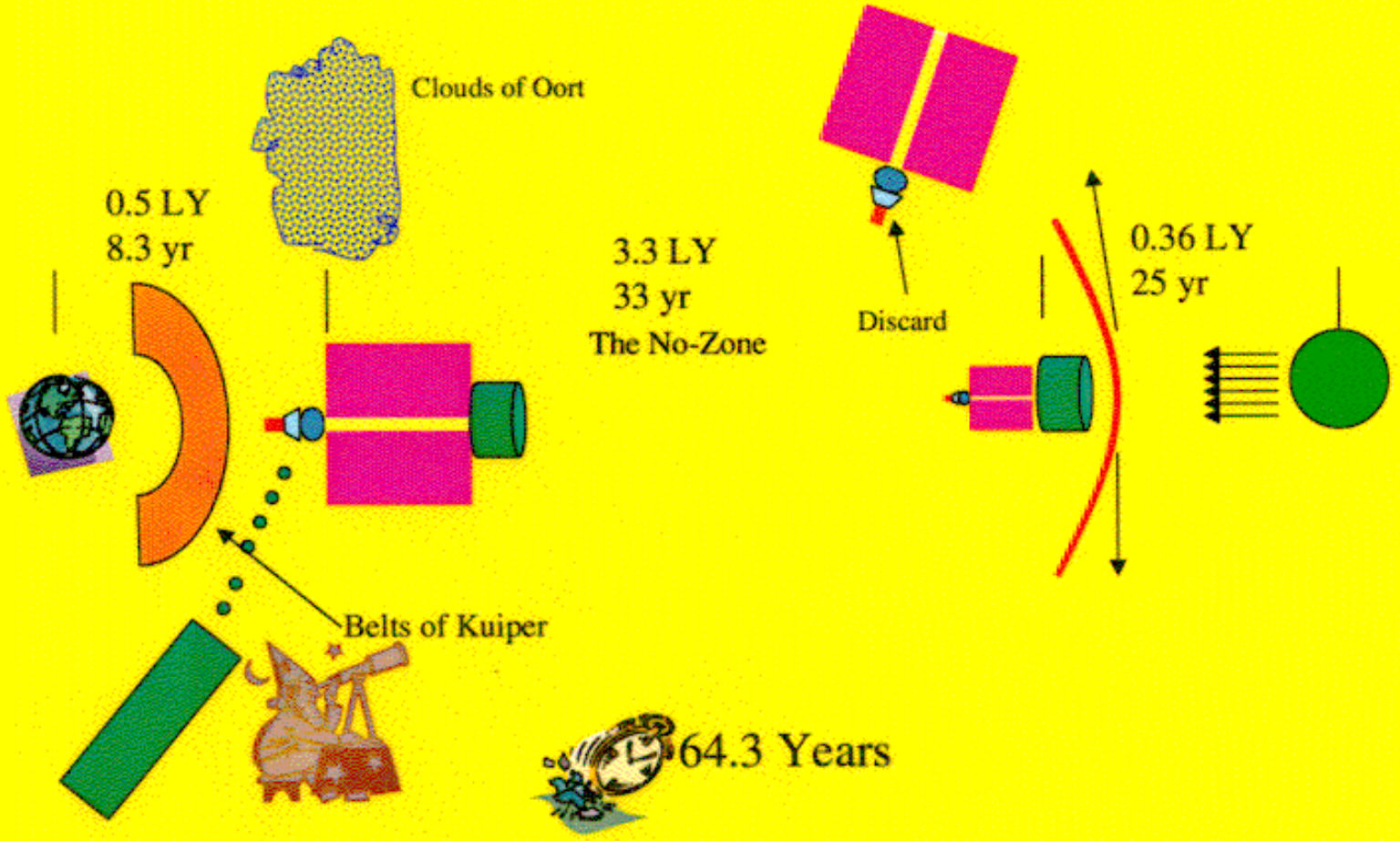
The Primary Problem is Decelerating at the Target System

# Acceleration Issues

- Fission Fragments for Ion Engine Propellant
- Total System Balance Requires Specific I,,
  - **Vex** = SQRT(2*$\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$*8.64E13)
  - **Vex = 1.3** 14e07*SQRT($\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$)
  - $I_{sp}$= 1.34* SQRT($\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$) * $10^6$ sec
  - $M_{dot}$= Pwr/ (2*Ef*$\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$ )
  - **Thrust** = $m_{dot}$Ve = $m_{dot}$SQRT(2*$E_f$*$\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$)
  - $m_f = m_i$*exp($\Delta V/gI_{sp}$) = $m_f$e(3X107/SQRT(2*$E_f$*$\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$))
  - **Thrusting time:** = mf-mi/(Pg/ 2*$E_f$*$\eta_{th}$ * $\eta_{pr}$ * $\eta_{ion}$)
- 'Once conversion and ion engine efficiency known all parameters determined
- If complete deceleration by fission power not required, acceleration appears tractable


Specific Impulse vs. System Efficiency
1400000
1200000
1000000
800000
600000
400000
200000
0
Isp
0.5
0.6
0.7
0.8
0.9
Combined Efficiency

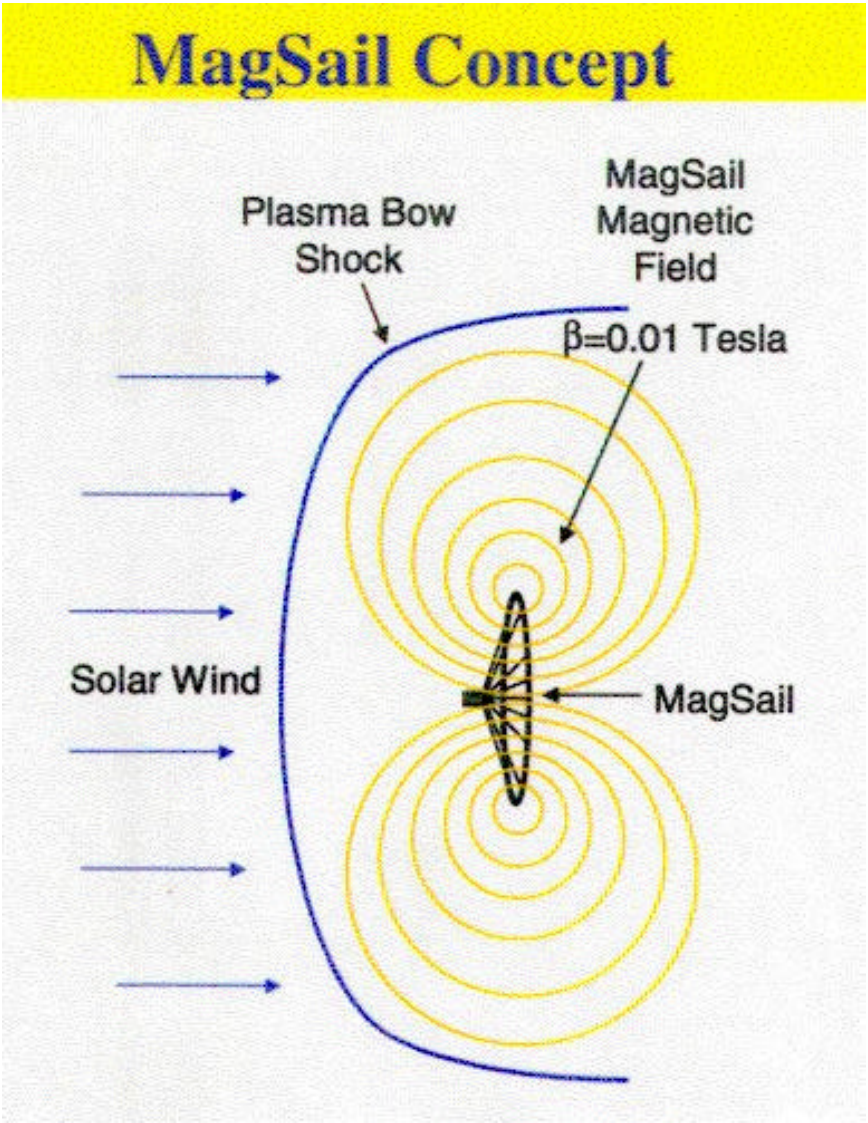
# Proposed Transportation Concept



# Issues Bearing on Problem

- **Does a Technological Mechanism Exist to Overcome Deceleration Problem?**
- **External Systems Require Pre-Deployed Assets at Target Star System**
  - Clusters of nano-bots to build system-level accelerator, e.g.
  - Requires use of completely unforeseen capabilities in nano-bots
  - Requires **us** to **get the nano-bots** there
  - Must have mapped out target system and resources prior to arrival
  - **Competition with** Extant Societies?
  - Extremely Complex **Solution**
  - Still Retain Aiming Problems
  - Never truly independent exploration; years to establish **infrastructure**
- **Proposed Solution: Employ MagSail; Trap Target System Solar Wind for Deceleration**

# MagSail Concept



# Preliminary MagSail Parameters

- Detach Primary Power System From Habitat: Sheds 700T
- Yields 20 MW Power System plus Crew Module
- Unfurl MagSail at 24,000 au
  - **Diameter: 300,000 meters**
  - **Current: 530,000 amp-turns**
  - **Interstellar Density 100,000**
  - **Initial Deceleration: 0.5 $m/s^2$**
  - **Decelerate for 5.7 years to 7,430 km/s**
- Increase MagSail Size at 7400 au
  - **1 amp-turn: 265,000 amps**
  - **Secondary Deceleration: 0.12 $m/s^2$**
  - **Decelerate to 1000 km/s**
  - **Decelerate for 12.2 years**
- Begin Final Ion Thruster Deceleration to Star System

# Possible Future System Specifications

- Existing **Brayton** Turbo-Machinery is on Trend Line Toward ~$10^{-3}$ **kg/kWe** For Large Systems
- Alternator Systems Follow Trend Line of $10^{-3}$ **kg/kWe** for Large High Speed Systems
- Reactors (e.g. Pebble-Bed) Could Achieve <$10^{-3}$ **kg/kWth**
- Radiator (Using Solar Sail Technology?) <$10^{-3}$ **kg/kWth**
- Advanced Neutral Beam Fusion Injectors <$10^{-3}$ **kg/kWe**
- Specific Mass ~1X$10^{-3}$ **kg/kWe**
- Crew Habitat, **Baseload** Power and Life Support ~200T
- **MagSail** System 100T
- Total Mass 1000T Yields -700 GW electrical power

# Interstellar Performance

- If $10^{-3}$ kg/kWe Feasible, Accelerator Provided U-235 Yields Acceleration Times of 8.3 Years to 0.1c
- If System Carries all U-235 Acceleration Time -40 Years – Possibly Impractically Long – However no Particle Accelerator Necessary
- **Distance is -0.5 LY; Possibly** Feasible with Advanced NPB Aiming
- **~20MW Power System** for Housekeeping Power During Trip and Deceleration
- If Power System Masses ~ $10^{-4}$ kg/kWe; No Particle Beam is Necessary and **Acceleration** Times Short
- Key is **Mag Sail** Performance

# Summary

- There's Still No Free Interstellar Lunch
- MagSail Decreases Particle Beamed Mass by 11,200+ T o n s
- Decreases Societal Energy Requirement by ~$10^{22}$ Joules
- Advances in Superconductors Would Help
- Trip time not Inconsistent with Increasing Life Spans
- A Breakthrough in Propulsion Physics Would be Nice